# I. Introduction

## A. Summary

This paper addresses two primary topics: 1. estimating the fatigue life of the main load carrying bearings in movable bridges and 2. specifying bearings for use in movable bridges.

Main load carrying bearings in bridges are unique in bearing applications because of their extremely long design life: 75 or 100 years are common life expectancies. Till now a static load rating safety factor was used to size these bearings and using the heavy duty 232 series spherical roller bearings it assures that with proper maintenance the bearing will not fracture. But since bearings are critical components in the long term performance and safety of movable structures it is appropriate to address their fatigue lives. However their slow rotating speeds result in a very low lubricating film condition with metal to metal contact leading to wear and surface fatigue. Therefore standard ISO and ABMA equations require special factors. A method of estimating fatigue life is presented as an additional parameter to consider in predicting service life.

The second section is a detailed description of a checklist of issues to address in specifying bearings for movable bridges so they will perform as required. The intention is to have these issues covered early in the design stage to expedite manufacture, delivery, storage, and mounting and avoid changes and compromises. Bearing housings, seals, lubricant, mounting, shipping, and storage are covered.

This paper will primarily address rolling element bearings for: bascule bridge trunions, large vertical lift bridge sheaves, and swing bridge center pivots. Many of the comments in the section on specifying bearings pertain to any rolling bearings used in heavy movable structures with the general assumption that rotating speeds are low.

## B. Selection of bearing type

1. For trunion bearings in bascule bridges the choice is generally between non-self aligning bronze sleeves and spherical roller bearings. Self-aligning plain bearings with their high frictional torque, short life due to wear from contamination, and significantly higher cost (considering bearing and housing) are rarely used. Non-self aligning bronze sleeves are significantly less expensive than rolling bearings and are considered where life requirements are very low, misalignment maintained and controlled, and high, variable friction torque is acceptable.

2. Bearings in vertical lift bridges undergo several complete revolutions in opening and closing the bridge and this increased rotation makes spherical roller bearings the primary consideration for their longer life and reduced power requirements.

3. For swing bridges the choice is generally between custom made spherical plain bearings and spherical roller thrust bearings. Custom made spherical plain bearings have a shorter service life and higher friction requiring more power to operate. Spherical roller thrust bearings have a higher contact angle resulting in increased stability and thus less sensitivity to seismic or impact loading from vessels or floating debris.

# II. Fatigue life in rolling bearings

## A. The theory

The first consideration in selecting trunion and sheave bearings is shaft diameter based on loading. Once the minimum shaft diameter is established then bearing load rating comes into consideration. For swing bridge center pivots, bearing size is based on static safety factors and required life. Bridge loading is the primary consideration as there is negligible moment load applied to the stub shaft.

For bridges with few openings and thus low bearing usage a static safety factor, as defined by AASHTO, serves as a good measure to determine bearing size. Static safety factor doesn't estimate how long the bearing will last; it assures that the bearing will not fracture as long as it is properly mounted and lubricated. However for bridges which will require significant bearing service, fatigue life should also be evaluated. Fatigue life does not replace static safety factor it is another number to consider in selecting a bearing.

NOTE: For the purposes of this paper "service life" will refer to the number of cycles a bearing undergoes. For bascule trunion and swing bridge center pivot bearings, each opening and closing is considered two cycles. For vertical lift bridges the number of cycles is the number of bearing revolutions for each opening and closing of the bridge.

In 1947 Dr. Arvid Palmgren, Director of research for SKF and his assistant Gunner Lundberg, published a fatigue life theory for ball and roller bearings:

$$L_{10} = (C/P)^{p}$$

Where:

 $L_{10}$  = the basic bearing theoretical fatigue life, at 90% reliability, in millions of revolutions.

- C = bearing dynamic load rating, in pounds or newtons.
- P = bearing equivalent applied load considering both radial and axial load, in pounds or newtons.
- p = the exponent of the life equation
- = 3 for ball bearings
- = 10/3 for rolling bearings

This basic relationship, with environmental adjustment factors, is still in common use today showing its universal applicability and general accuracy. It was adopted by the ISO in 1962.

Table 1, gives a brief history of bearing fatigue life equations. It shows that the original rolling bearing relationship, and particularly the term,  $(C/P)^p$ , has not changed. Only the adjustment factors have changed. In 2007 the ISO adapted an  $a_{ISO}$  environmental adjustment factor that can account for contamination and lubricant viscosity to adjust bearing fatigue life.

1947 to 1962	$L_{10} = (C/P)^{p}$	Lundberg Palmgren, ISO 281
1962	$L_{10} = a_{23} (C/P)^{p}$	SKF
1967	$L_{10} = a_2 a_3 (C/P)^p$	ISO 281 (operating conditions)
1989	$L_{10} = a_{SKF} (C/P)^{p}$	SKF (fatigue stress limit)
1990	$C = b_m C_{old}$	ISO 281
2001	$L_{10} = a_{xyz} (C/P)^{p}$	ISO Life mod. factor (ISO281-2)
2002	$L_{10} = a_{SLF}(C/P)^{p}$	ASME Bearing Guide
2003	$L_{10} = a_{DIN}(C/P)^{p}$	DIN ISO 281
2007	$L_{10} = a_{ISO}(C/P)^{p}$	ISO 281:2007

Table 1, Historical evolution of bearing fatigue life equations

B. Lubricant film in rolling bearings

For a bearing to achieve optimum life it requires a lubricant film that sufficiently separates the rolling surfaces. The effectiveness of the lubricant is primarily determined by the degree of separation between the rolling contact surfaces. To form an adequate film the lubricant must have a given required minimum viscosity at the bearing operating temperature. This minimum required viscosity is primarily determined by the bearing size and rotating speed. Lower speeds require higher minimum viscosities. An effectiveness parameter of the lubricant film is the viscosity ratio, Kappa: the ratio of the actual oil viscosity, v, divided by the minimum viscosity,  $v_1$ :

$$K=v\!/\!v_1$$

Where:

K = Kappa, the viscosity ratio

v = the actual viscosity of the lubricating oil at operating temperature, mm<sup>2</sup>/sec

 $v_1 =$  the rated minimum viscosity, depending on bearing mean diameter and rotational speed,  $mm^2/sec$ 

Appendix 1 shows how to calculate Kappa using the SKF Interactive Engineering Catalog.

Figures 1, 2 and 3, graphically illustrate rolling contact at varying values of Kappa:



Figure 1, Full Film Lubrication: K >1



Figure 2, Mixed Lubrication: K< 1.



Figure 3, Boundary Lubrication: K<<1.

## C. Predicting fatigue life

Because of the very low rotating speeds virtually all trunion, main sheave, and center pivot roller bearings in bridges operate at a boundary lubrication condition. So to predict fatigue life it is necessary to use a new adjustment factor. The equation is:

$$L_{10} = a_{\text{special}} (C/P)^{10/3}$$

Where:

- $L_{10}$  = the basic bearing theoretical fatigue life, at 90% reliability, in millions of revolutions.
- C = bearing basic dynamic load rating, in pounds or newtons.
- $a_{special}$  = the special adjustment factor for boundary lubrication. This can be varied for life extending features like improved steel and coatings.
- P = equivalent applied dynamic bearing load, accounting for both radial and axial loads, in pounds or newtons
- 10/3 = the roller bearing exponent of the basic life equation, from Lundberg/ Palmgren.

After analysis of some pertinent test results and in consideration of the estimated lives of bearings in existing bridge applications SKF has developed a set of  $a_{special}$  factors applicable to large, very slow speed bridge bearings. Different factors are used for different bearing features:

- 1. Standard bearings.
- 2. Bearings using either SKF XBite.
- 3. Bearings that have rollers with NoWear coating.
- 3. Bearings with both NoWear and XBite.

Table 2, shows a sample calculation:

	Years	Open-	Total	Applied			Static	Dynamic	AASHTO	Est	Requ-	AASHTO
	of	ings	cycles	radial		Bearing	load	load	Equiv Static	Fatigue	ired	Ns =
	bridge	per	req'd=	load:	Bearing	Bore	rating:	rating:	load=	life=	capacity=	Co /
	service	day	cycles/	Fr	Number		Co	С	Paashto	L10	Creq'd	Paashto
			10^6	kips		inches	kips	kips	kips	years	kips	DIM
1	75	20	1.095	1,200	232/560	22.047	4,950	2,590	1,524	38.580	3,162	3.25
2	75	20	1.095	1,200	232/560	22.047	4,950	2,590	1,524	50.153	2,922	3.25
3	75	20	1.095	1,200	232/560	22.047	4,950	2,590	1,524	69.443	2,650	3.25
4	75	20	1.095	1,200	232/560	22.047	4,950	2,590	1,524	88.733	2,463	3.25
5	75	20	1.095	1,200	232/530	20.866	4,590	2,500	1,524	78.865	2,463	3.01
6	75	20	1.095	1,200	231/670	26.378	5,040	2,450	1,596	63.325	2,578	3.16

### **Example Calculation Sheet for Spherical Roller Bearings in Bridges**

Table 2, an example calculation sheet for fatigue life and AASHTO Safety factor for large, very slow speed spherical roller bearings in a bascule bridge. The different lives for the 232/560 bearing are the result of varying the special life adjustment factor.

In the example shown the required bearing life is 75 years with 20 openings per day. A 232/560 basic bearing is selected and the calculation is performed with various combinations of improved steel grade (XBite steel) and roller coating (NoWear). Note that the AASHTO safety factor, Ns, doesn't change unless the bearing changes but with improved performance parameters the estimated fatigue life, in years, changes so that for the standard bearing with no improved steel or coatings the life is only 38+ years, whereas by applying the associated factors the estimated fatigue life can be improved to 88+ years. So with these features a smaller, 232/530 bearing, can meet the required life.

Life predictions using this new method are interpretive and experience is limited so please contact SKF Applications Engineering for a complete analysis and bearing validations and recommendations.

#### D. XBite Steel<sup>®</sup>

XBite steel is AISI 52100 bearing steel that has been processed using a new heat treatment that yields through-hardened steel with increased hardness while maintaining toughness. It has

greatly improved wear properties especially under conditions of poor lubrication and/or contamination. Fig. 4 shows the results of laboratory tests comparing SKF Explorer grade bearings made from XBite to previously standard SKF and various other manufacturers' bearings. Each bar is a statistical average of 35 test runs. Note that these tests were performed on SKF Explorer Grade bearings which include other design features beside XBite steel. At this time all SKF large bearings do not have the other design features, only the XBite steel, so the a<sub>special</sub> accounts for the difference in performance. Note that the improvement is significant.



Fig. 4, bearing life comparison between SKF Explorer Grade, SKF previous standard grade, and various other bearing manufacturers.

## E. NoWear<sup>™</sup> Coating

The boundary lubrication in slow speed bridge bearings allows metal-to-metal rolling contact that leads to micro welding which damages rolling surfaces. Also small, vibratory movements between rolling surfaces when the bearings are not rotating can result in false brinelling which also damages rolling surfaces. SKF NoWear is a hydrogenated, amorphous carbon coating that consists mainly of carbon with a metallic bonded inter-layer giving diamond-like performance.

This non-metallic surface protects against the damage caused by micro welding and false brinelling. Fig. 5 shows the results of the standard Fafnir false brinelling test. The wear, measured in mg, is reduced by a factor of roughly 10.



Fig. 5, results of the standard Fafnir test, comparing NoWear coated bearing elements to plain un-coated steel surfaces.

## F. Conclusion

Virtually all main bridge bearings operate at very slow speeds that result in boundary lubrication. The basic relationship between fatigue life,  $L_{10}$ , basic dynamic load rating, C, and applied load, P, is unchanged over many years of analysis and testing. So that same relationship is used to predict fatigue life for bridge bearings using special adjustment factors,  $a_{special}$ , to account for the boundary lubrication.

These factors have been developed for standard bearings, bearings of high performance XBite steel, bearings with NoWear coated rollers, and bearings with both XBite steel and NoWear coated rollers. Since the resulting life predictions are somewhat interpretive please contact SKF Applications Engineering for this analysis.

# III. Specifying bearings for movable bridges

## A. Bearing housings

The following recommendations are for large trunion and tower sheave bearings that are mounted directly onto tapered shafts and for the smaller split pillow block bearings that are mounted on adapter sleeves.

#### 1. Seals

Keeping bearings clean is necessary to achieve long life so sealing them is a primary concern. Following are general seal recommendations for slow speed bearing used on movable bridges. Note that misalignment values given are maximum allowable values. The more accurately a seal is aligned the better it will perform so values of half maximum allowable will yield improved performance. For seals with very low maximum allowable misalignment achieving half of that value may not be practical. There is a complete description of the designations for pillow blocks, including seals, given in Appendix 3.

a. For safety critical bearings or bearings exposed to a harsh environment supporting shaft diameters above 9" the triple lip seal is recommended. This seal provides maximum exclusion of contamination while retaining grease within the housing. The triple lip seal can accommodate 0.062" of maximum radial misalignment (measured at the seal lip) and an inboard seal can be replaced without dismounting the bearing. Fig. 6 shows this seal. Note provision for adding lubricant between the two outer lip seals to purge contaminant. The suffix designation for this seal is "HST".



Fig 6, the triple lip seal

b. For safety critical bearings or bearings exposed to a harsh environment supporting shaft diameters up to 10" a Taconite seal can be used. This seal provides very good exclusion of contamination, less than the Triple Lip seal, while retaining grease within the housing. However it can only accommodate a maximum of 0.010" of misalignment and an inboard seal cannot be replaced without dismounting the bearing. Fig 7 shows this seal. Note that this seal also has provision for adding grease between the lips to purge contamination. The suffix designation for this seal is "T".



Fig. 7, the Taconite Seal

c. SKF now offers the HS seal. This is a single lip seal with good exclusion of contamination but not as good as the Taconite seal. It is available in virtually all shaft sizes and it can accommodate a maximum misalignment of 0.062". It requires a clamping plate that can be removed to replace an inboard seal. Fig. 8 shows this seal. The suffix designation for this seal is "HSS".



Fig 8, the SKF Sealing Solutions HS Contact Seal

d. For most housings with up to 10" diameter shafts a labyrinth seal with an included rubber lip seal is supplied as standard. This seal provides slightly less exclusion of contamination than the HS seal. It can accommodate  $0.5^{\circ}$  of misalignment and an inboard seal cannot be replaced without dismounting the bearing. The SKF version of this seal is called the PosiTrac Plus Seal; illustrated in Fig. 7. The suffix designation for this seal is "TLC".



Fig. 9, the SKF PosiTrac Plus Seal

e. SKF also offers a single lip contact seal that is retained in the housing by circumferential compression of the fiber reinforced rubber. This seal provides slightly less exclusion of contamination than the PosiTrac Plus seal. It can accommodate 0.030" of misalignment and an inboard seal cannot be replaced without dismounting the bearing. This seal is illustrated in Fig. 9. The suffix designation for this seal is "C1".



Fig. 10, the standard contact seal

f. The standard seal for all SKF split pillow blocks is the Triple Ring Seal. Referred to as the LER seal, it is the standard labyrinth seal commonly used in Imperial (inch) pillow blocks throughout North America. It is not to be confused with the Triple Lip Seal. It uses the same ring as the PosiTrac Plus Seal except it has no lip seal and no "O" ring to secure it to the shaft. It can accommodate 0.5° degrees of misalignment and an inboard seal cannot be replaced without dismounting the bearing. This seal is supplied if there is no suffix at the end of the part number.

Table 3 gives a comparison of the relative cost and functional properties of the seals that are commonly used in bridge applications. Note that there are other seals available for specific needs that may arise. Contact applications engineering for recommendations.

Seal	Relative sealing	Relative cost	Size range	Maximum Misalignment Capability	Inboard seal Replaceable Without Removing bearing	Suffix Designation
Triple Lip	++++	++++	Above 9"	0.062"	Yes	HST
Taconite	+++	++++	Up to 10"	0.010"	No	Т
HS type	++	++	Any	0.062"	Yes	HSS
PosiTrac Plus	++	No adder	Up to 10"	0.5°	No	TLC
Standard Contact	+	+	Up to 8"	0.030"	No	C1
Triple Ring	Average	No adder	all	0.5°	No	Blank

Table 3, Comparison of various seals commonly used for bridges.

#### 2. Closed end housings

Housings can have either both ends open or only one end open. If the shaft can end inside the housing then it is preferred to have one end of the housing closed to eliminate the need for sealing the rotating shaft. Housings should be specified as to "One End Closed", designated by the suffix "A", or "Both Ends Open", designated by the suffix "B".

#### 3. Shaft and housing fits

Virtually all bearings in heavy movable structures have tight inner ring and loose outer ring fits. Tight inner ring fits eliminate shaft damage caused by fretting corrosion. While loose outer ring fits allow the outer rings to slide axially to accommodate shift in the structure, thermal expansion, and mounting inaccuracies. One notable exception would be the fixed trunion design where the bearing outer ring rotates and the inner ring is stationary. Here the outer ring has an interference fit and the inner ring is loose. Fits should be reviewed by a bearing Applications Engineer and specified.

#### 4. Fixed or floating

Usually one bearing on each shaft has its outer ring axially fixed to locate the shaft axially while all other bearings on the shaft have outer rings that are floating. Deviations from this should be reviewed with SKF Applications Engineering. All housings should be specified as to fixed or floating: fixed is designated by the suffix "F", and floating, is designated by the suffix "L".

#### 5. Housing material

Unless otherwise specified SKF steel housings are ASTM A27 Grade 60-30 for castings and ASTM A36 plate for fabrications. It should be specified that housings are to be made of steel if steel is required. By adding an "S" at the end of the housing prefix standard steel will be supplied. For example in the prefix SAFS the second S designates a cast steel housing.

#### 6. Cap and base bolts

SKF supplies cap bolts for its housings that are appropriate for the housing load ratings. For steel housings all cap bolts are either ASTM A354 Grade BD or SAE J429 Grade 8. SKF does not supply base bolts but a good rule of thumb is to use the same grade and diameter bolt as is used for the cap bolts. There is no need to specify cap bolts for steel housings.

#### 7. Base bolt holes

SKF housings for bridge applications are supplied with solid, un-cored housing feet. It is strongly recommended that undersized pilot holes be specified to control the location of the base bolt holes. Unless otherwise specified solid housing feet are supplied.

#### 8. Quality specifications

In order to insure the accuracy and integrity of its housings SKF designs and tests them to the following specifications and it is recommended that all safety critical housings for bridges meet these standards.

- a. All housing design is to ISO 9001 standards to assure the highest level of quality and traceability of revisions.
- b. Housings that are safety critical should have an ultrasonic inspection by a level 2 inspector per EN 473 or ASNT SNT-TC-1A. The acceptance level for UT is quality level 2 for the test areas and quality level 3 for the rest of the housing per Table 1 of EN 12680-3 for wall thickness greater than 200 mm.
- c. Housings that are safety critical should also be magnetic particle inspected for surface cracks to a quality level 3 per EN 1369

It is also recommended that housings and bearings be designed and manufactured by the same bearing company to assure compatibility.

### 9. Housing paint

Housing paint has a history of creating problems for bridge builders. Unless otherwise specified SKF standard Acrylic Enamel is applied. If alternate paint is required it should be called out.

### 10. Pedestal flatness

If housings are mounted to a pedestal that is not flat two problems can arise: 1. the housing bore can be distorted to pinch the bearing outer ring and prevent it from floating freely in the housing thus leading to excessive axial load on the bearing. 2. The outer ring of the bearing can be distorted so that the load is not distributed evenly thus shortening bearing life. It is recommended to hold flatness on the pedestal to within 0.002" per foot of bearing housing width. So a 36" wide housing should be mounted to a pedestal that is flat within 0.006" across the width of the entire housing. This usually requires a machined surface that has had no welding done to it after machining.

## B. Lubrication

1. Split pillow block and large special bearings are provided without grease. For spherical roller bearings grease lubrication, as opposed to oil, is recommended in virtually all bridge applications. For the main trunion bearings for bascule bridges and the main sheave bearings for vertical lift bridges grease with a calcium sulfonate thickener is recommended. This thickener provides excellent corrosion and water resistance as well as extreme pressure protection under boundary lubrication. Greases that use Molybdenum Sulfide should be avoided since this additive can become corrosive in the presence of moisture. The SKF grease that meets all of these criteria is designated LGHB2. This grease is also excellent at lubricating most other bearing used in bridges, including most, but not all, plain bearings.

2. For spherical roller thrust bearings used for the center pivot bearing in swing bridges oil lubrication is generally recommended since the bearing can be filled entirely with oil without relying on seals to retain the oil. See SKF Applications Engineering for specific oil recommendations.

3. Automated lubrication systems can provide great benefits to bridge bearings to assure optimum long term performance of the bearings. These systems can provide lubrication to all of the bridge components that require grease. The Kilbourn Ave. Bridge in Milwaukee uses an SKF Automatic lubrication system. Fig.'s 9 and 10 illustrate it.



Fig. 9, an overview of an SKF/ Vogel lubrication system



Fig. 10, schematic view of the Kilbourn Ave. Bridge Lubrication system.

## C. Mounting

1. The large trunion and sheave bearings are best mounted using matching tapers on the shaft and bearing bore. Hydraulic features are to be machined in the shaft and a clamping plate bolted to the end of the shaft. The bearing can be driven up onto the taper using hydraulic oil and the clamping bolts. The bearing can be dismounted by loosening, but not removing, the clamping bolts and then using the hydraulic features on the shaft. The dimensions of the hydraulic features are specified by SKF but the manufacturer of the shaft is responsible for machining them. Similarly the clamping plate and bolts are specified by SKF but supplied by the manufacturer of the shaft. The threaded hole for the hydraulic feature should be plugged after assembly to exclude contaminants. 2. For bearings above 160 mm bore that are mounted on adapter sleeves, hydraulic mounting features are required for proper mounting and dismounting and should be called out in the specification of the bearing.

3. It is recommended that an authorized bearing technician be present to supervise the mounting of all bearings. Starting and final values for radial internal clearance should be recorded and kept on file for use in assessing the bearings in the future.

### D. Storage and Handling

1. All bearings must be stored in a climate controlled environment if they are to be stored for more than 3 days. The temperature should be maintained between  $20^{\circ}$ F and  $80^{\circ}$ F and the humidity should not exceed 80%.

2. Bearings should be handled with the utmost care with safety and cleanliness as prime considerations. Once the bearing is removed from the packaging it was shipped in it must be kept immaculately clean and dry until it is mounted in its housing and the housing is filled with grease.

3. If bearings are not mounted on site and thus must be shipped to the site after removing from original packaging they must be assembled into their housings and the housings should be filled 100% full of lubricant for shipping. Also the shafts must be secured with a significant load so there can be no movement or vibration of the bearing that could cause false brinelling during shipping. SKF Application Engineering can supply the load required to secure the shaft.

4. There should be no arc welding near or across a bearing.

## E. Conclusion

Specifying bearings for bridges entails a broad list of items to consider. The objective here is to provide a checklist of items that should be considered to assure that the proper bearing is specified and that it will perform as required without need for iterative inquiries after the bearings have been specified.

## References

1. <u>Load Ratings and Fatigue Life for Roller Bearings</u>; American National Standard AFBMA Std. 11-1990 (July 17, 1990)

2. <u>Dynamic Capacity of Rolling Bearings</u>; Lundberg, G. and Palmgren, A.; Acta Polytechnica; Mech. Eng. Vol. 1. No. 3 (1947)

3. SKF Interactive Engineering Catalog; www.SKF.com

4. <u>A New Fatigue Life Model for Rolling Bearings</u>; Ioannides, E. and Harris, T. A.; ASME Journal of Lubrication Technology, Vol. 107, pp 367 to 378 (1985)

5. <u>Standard Specifications for Highway Bridges</u>; American Association of State Highway Transportation Officials, (2004)

6. <u>Specifications for Steel Railway Bridges</u>; American Railway Engineering Association, Manual for Railway Engineering, Chapter 15, Steel Structures, (1993)

7. <u>An Analytical Formulation for the Life of Rolling Bearings</u>; E. Ioannides, G. Bergling, A. Gabelli; Acta Polytechnica Scandinavica, Mechanical Engineering Series No. 137, 1999

8. <u>Rolling bearings - Dynamic load ratings and rating life;</u> International Standard ISO 281:2007

# Appendix 1

# Calculating Kappa using the SKF Interactive Engineering Catalog

1. To calculate Kappa the following parameters are required: 1. the bearing number or its size, 2. the approximate operating temperature, 3. the viscosity of the lubricant in centistokes, 4. the bearing rpm, and 4. the applied loads in newtons (1 pound = 4.4482 newtons)

2. On the internet go to SKF.com. Fig. 1 shows the opening page.



Fig. 1, the opening page for "SKF.com"

- 1. Select "Rolling Bearings" and then on the next page select "Calculations"
- 2. This will open the "Calculations" page listing all the calculations that are available. Left click on the "Bearing Life" selection under Rolling Bearings to open the "Bearing Life" data input page.
- 3. Next to the bearing heading left click on the blue "Select Bearing" selection. Note that any text that is blue can be selected with a left click for further information to help with calculating the required data.
- 4. This will open the "Designation Search" page. If the bearing designation is not known, a bearing can be selected by a left click on the type of bearing. Doing this will open a catalog listing of bearings for selecting the one of interest. If the bearing designation is known it can be entered at the space provided at the top of the "Designation Search" page. In this case a 232/560 bearing is entered and the "Search" tab is left clicked.

- 5. This opens a listing of all the various ways this bearing is offered: a 232/560 CAK/W33 is selected. This will input the bearing data and open the "Bearing Life" page. Note that for virtually all bearing manufacturers the suffix "K" designates a tapered bore bearing and "W33" designates a circumferential oil groove around the OD of the bearing outer ring with several through holes to provide lubrication between the two rows of rollers.
- 6. Next left click on "P, kN" to enter the applied load. This opens the "Equivalent bearing loads and basic rating life" page. Enter the applied radial load, "Fr, kN", and axial load, "Fa, kN", in kilo-Newtons. For this example the same radial load from Table 2, is used. That value is 1200 kips; divide by 0.225 to convert to kN (kilo-Newtons): Fr = 5333kN. As set by AASHTO Fa is set at 15% of Fr: Fa = 800 kN. Now left click "Calculate" to perform the calculation. Closing this page opens the "Bearing Life" page and enters the calculated Equivalent Dynamic load.
- 7. Enter the bearing RPM in the "n, r/Min" space.
- 8. Next the viscosity of the lubricating oil is input; if grease is used this is the base oil viscosity. The blue "v, mm<sup>2</sup>/sec" could be selected to calculate viscosity but for this example the value of 1000 mm<sup>2</sup>/sec is used to represent the highest base oil viscosity that can be presumed to be practical for an extended time and at varying temperatures.
- 9. Fig, 2 shows the resulting "Bearing Life" page. For this example using a 232/560 bearing and a lubricant with a viscosity of 1000 mm<sup>2</sup>/s rotating at 1.75 RPM the program does calculate bearing life. If any lower speed is input the program will not calculate bearing life. So for these parameters 1.75 RPM is the lowest speed that can be used to get a reasonable, adjusted bearing life. For speeds below 1.75RPM, lubrication is inadequate and the program will not calculate an adjusted life.

#### Summary:

For any slow speed bearing it is recommended to calculate Kappa to assure that the grease selected will provide an adequate lube film to protect the rolling surfaces and assure optimum bearing life. This example shows a convenient way of calculating Kappa and could be used on pinion, drive, and any other slow speed bearing used in a bridge. For large bascule bridge trunion, swing bridge center pivot, and vertical lift bridge bearings, rotating speeds are almost always too slow to provide adequate lube film; even with the highest viscosity lubricants. In these cases special life adjustment factors are necessary to predict bearing fatigue life.

Every be acc out of	care has be cepted for a the use of t	een taken to ensur ny loss or damage he calculation.	e the accura whether dire	cy of this calcula ect, indirect or co	tion but no liability ca onsequential arising
See se	ection "SKF	rating life"			
		Bearing	232/	560 CAK/W33	
Select	n <sub>c</sub>	d, mm	560		
0.5	-	D, mm	1030	1	
		C, kN	1150	10	
		P <sub>u</sub> , kN	1400	5	
		P, kN	685	3	
		n, r/min	1.75	;	
		v, mm²/s	100	0	
			Ca	lculate )	
		L <sub>10</sub>	6	L <sub>10h</sub>	53500
к	1.01				
v <sub>1</sub>	987				
a <sub>SKF</sub>	0.366	L <sub>10m</sub>	2	L <sub>10mh</sub>	19600
Old a <sub>2</sub>	3 method fo	r comparison			
a23	1.01	L <sub>10a</sub>	6	L <sub>10ah</sub>	54000
For gr	ease lubrica	ted bearings, plea	se check the	grease life. See	section "Grease

Fig. 2 shows a completed bearing life calculation.

## Appendix 2

## Lubrication in Rolling Bearings

### 1. The film

The film of lubricant that separates the rolling elements from the raceways of a bearing is of utmost importance to its performance. So this film has become a topic of intensive research for bearing manufactures and researchers. It is referred to as an <u>elastohydrodynamic</u>, EHD, film. Figs. 1, 2, and 3 show the test rig used to analyze the lube film: a steel ball is rolled over a rotating piece of quartz glass in the presence of a film of oil. By looking through the glass with a microscope the film can seen and since the light reflecting through the film changes wavelength and thus color the thickness of the film can be measured by the varying colors.



Fig. 1, a schematic view of a test rig used to measure the thickness of the oil film in a rolling bearing.



Fig. 2, a close up photograph of the steel ball rolling on the quartz glass



Fig. 3, an overall view of the test rig used to measure lube film thickness

Fig. 4 gives an overall view of the contact between the rolling element and its raceway. The contact ellipse is short and rounded in ball bearings and long and narrow in rolling bearings. And Fig. 5 shows the relative thickness of the lube film.



Fig. 4, an overall view of the deformation and contact ellipse in a rolling bearing.



Fig. 5, the relative thickness of the lube film in a rolling bearing.

Fig. 6 illustrates the properties of the elastohydrodynamic film. At 350,000 PSI the oil is compressed by 30% in volume and its physical properties change drastically. It has the viscosity of glass and the tensile strength of silver. A particle of smoke is bigger than the thickness of the film and will disrupt the transfer of force. The film is thickest in the middle and about half as thick around its perimeter.



## 2. Conclusion

The phenomenal lubricant film that is so important to rolling bearings is being analyzed and increasingly understood. This knowledge can be applied to evaluate the film by calculating the parameter Kappa. Bearing applications should be analyzed to see if there is adequate lubrication and if not, efforts should be made to assure that either: 1. a lube film is provided or 2. The lack of adequate lubrication is taken into consideration.

## Appendix 3

## Part Numbers for Specifying Bearing Housings for Bridge Applications

1. Following is a part numbering system to be used for specifying bearing housings for bridge applications. This system is to be used in the contract drawing and quoting phases to give a general description of the bearing and housing for consistent quotes and to save changes at the detail design phase. When the housings are designed in detail each will get its unique part number. This final drawing will give the name of the bridge and the contract identification number and this general descriptive part number.

_	S	_	Α	F	S	23252	Χ	9-1/2"	Α	L	HST
Ι	Ι	Ι	Ι	Ι	Ι	I		Ι	Τ	T	<u> </u>
Ι	Ι	Ι	Ι	Ι	Ι	I		I	Ι	Ι	I
Ι	Ι	Ι	Ι	Ι	Ι	I		I	Ι	Ι	I
Ι	Ι	Ι	Ι	Ι	Ι	I		I	Ι	Ι	I
1	2	3	4	5	6	7		8	9	10	11

- 1 \_\_\_\_ = cored feet with cast, slotted holes S = solid feet
- 2 Standard pillow block
- 3 \_\_\_ = standard design
- D = heavy duty design,
- 4 A = inch dimensions
- 5 F = triple ring seal unless changed by suffix in position 11
- 6 \_\_\_ = cast iron
  - S = steel
- 7 Housing designation from catalog (note: this # designates straight bore or adapter mounting)
- 8 Shaft diameter
- 9 A = one end closed
- B = both ends open
- 10 F = bearing axially fixed in housing L = bearing floating in housing
- 11 HST = Triple lip seal
  - T = Taconite Seal
    - HSS = HS single lip type seal
  - TLC = PosiTrac Plus Seal
  - C1 = Standard Contact Seal
  - \_\_= Triple Ring Seal

Table 1, Descriptive designations for bridge bearing pillow blocks



Fig 1, The Triple Lip seal, "HST"



Fig. 3, the HS seal, "HSS"



Fig. 5, the contact seal, "C1"



Fig. 2, The Taconite seal, "T"



Fig 4, the PosiTrac Plus Seal, "TLC"

Seal	Relative sealing	Relative cost	Size range	Maximum Misalignment Capability	Inboard seal Replaceable Without Removing bearing	Suffix Designation
Triple Lip	++++	++++	Above 9"	0.062"	Yes	HST
Taconite	+++	++++	Up to 10"	0.010"	No	Т
HS type	++	++	Any	0.062"	Yes	HSS
PosiTrac Plus	++	No adder	Up to 10"	0.5°	No	TLC
Standard Contact	+	+	Up to 8"	0.030"	No	C1

Table 2, Comparison of the seals commonly used for bridges.